NASA TECHNICAL MEMORANDUM

NASA TM X-71428

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ABSTRACTS OF NASA-ASRDI PUBLICATIONS RELEVANT TO AEROSPACE SAFETY RESEARCH

Aerospace Safety Research and Data Institute
Lewis Research Center
Cleveland, Ohio 44135
September 1973

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Compiled by
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Aerospace Safety Research and Data Institute
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

E-7681

FOREWORD

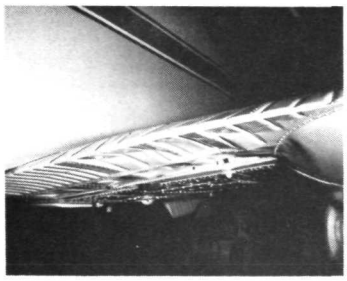
The mission and objectives of the Aerospace Safety Research and Data Institute are (a) to support NASA, its contractors, and the aerospace industry with technical information and consultation on safety problems; (b) to identify areas where safety problems and technology voids exist and to initiate research programs, both in-house and on contract, in these problem areas; (c) to author and compile state-of-the-art and summary publications in our areas of concern; (d) to establish and operate a safety data bank. As a corollary to its support to the aerospace community, ASRDI is also to establish and maintain a file of specialized information sources (organizations) and recognized, acknowledged experts (individuals) in the specific areas or fields of ASRDI's interest.

To match our resources with our priorties, ASRDI is concentrating on selected areas: fire and explosion; cryogenic systems; propellants and other hazardous materials, with special emphasis on oxygen and hydrogen; aeronautical systems and aircraft operations; lightning hazards; and the mechanics of structural failure. Staff expertise is backed by a safety library and is further supported by a computerized bank of citations and abstracts built from literature on oxygen, hydrogen, and fire and explosion. Computer files on mechanics of structural failure, fragmentation hazards, and safety information sources are also being established. In addition, ASRDI has two NASA RECON terminals and people adept at querying the system for safety-related information.

Frank E. Belles, Director
Aerospace Safety Research and Data Institute
National Aeronautics and Space Administration

AIRCRAFT LIGHTNING STRIKES

Aircraft Wing Distorted by Shock Waves Created by Lightning



ACCIDENT/INCIDENT REPORTS

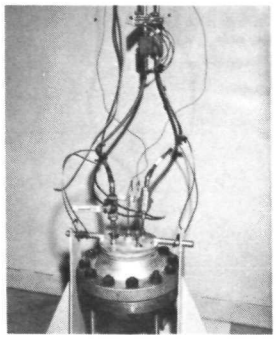
Car Burned in Oxygen Enriched Atmosphere

FIRE AND EXPLOSION

Burning Tests of Rooms Furnished with Fire Retardant Materials

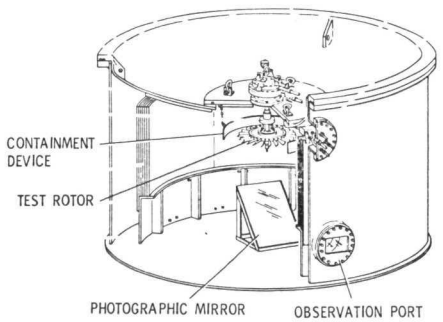
PROPELLANT HAZARDS

Reaction Chamber for Evaluating Behavior of Nonmetal Materials When Heated in Hydrogen



TURBINE ENGINE ROTOR BURST PROTECTION

Facility to Study Ways of Containing Fragments and Typical Test Results



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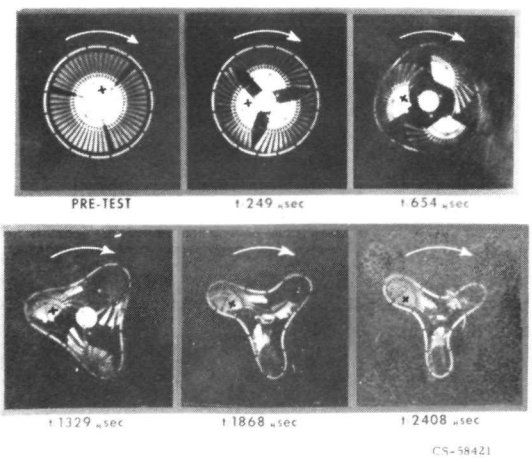

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ASRDI REPRESENTATIVE AREAS OF CONCERN

INTRODUCTION

ASRDI has initiated a number of safety research projects which are currently being perfromed in-house at Lewis and other NASA Centers and on contract with other government agencies and industrial organizations. Representative research programs include the following: fire protection on the shuttle and the orbiting workshop, lightning hazards to aerospace electrical systems, rotor burst protection for aircraft, improving aircraft braking systems, the safety problems involving the systems handling of cryogenic propellants, flaw growth tests of stainless steel pressure vessels, and the safety problems and hazards of complete systems, hardware, ground support equipment and facilities. A major program assigned to ASRDI by the NASA Administrator is the Oxygen Safety Review; the publications resulting from this program are described in this bibliography as individual volumes of the ASRDI Oxygen Technology Survey.

We conduct or sponsor research in the two broad areas of propellant and aviation safety. The work falls into two distinct categories:

(1) Hazard evaluation - defining a safety problem through an understanding of the physical phenomena involved

(2) Safety criteria - Measuring the effects of the parameters contributing to a hazard so that an appropriate degree of safety can be engineered into the system

From the field of propellant safety, an example of (1) might be a study of the properties of flames under weightless conditions, while an example of (2) might be measurements of the threshold energy for ignition of clean and contaminated Teflon by mechanical impact in high-pressure oxygen.

The results of research plus the collection and evaluation of existing safety data build the data bank of safety information. In part, this information is stored in the heads of experienced people and on library shelves. Where appropriate, machine techniques are used to store and retrieve data.

This compilation includes reports, journal articles, and symposium presentations prepared by ASRDI staff members as well as by contractor staff members. The indexes provide the guides to the author's organization. Inquiries about individual publications may be made by contacting the

Aerospace Safety Research and Data Institute, Lewis Research Center, 21000 Brookpark Road, Cleveland Ohio, 44135.

Telephone inquiries should be directed as follows:
(Commercial lines, 216) 433-4000 Ext. 285
(FTS, 216) 433-6285

ASRDI publications are also announced in the NASA journal, STAR (Scientific and Technical Aerospace Reports) available from the Government Printing Office, Washington, D.C. 20402, and in IAA (International Aerospace Abstracts), which is operated by the AIAA, 750 Third Avenue, New York, N. Y. 10017.

CONTENTS

ABSTRACTS OF NASA-ASRDI PUBLICATIONS RELEVANT TO AEROSPACE SAFETY RESEARCH

I. OXYGEN TECHNOLOGY

Roder, H. M.; and Weber, L. A.: ASRDI OXYGEN TECHNOLOGY SURVEY. I - THERMOPHYSICAL PROPERTIES. NASA SP-3071, 1972.

This desk-copy handbook evaluates the data on properties of oxygen and provides the user with that information, which in the judgment of the authors is most useful.

Bankaitis, H.; and Schueller, C. F.: ASRDI OXYGEN TECHNOLOGY SURVEY. II - CLEANING REQUIREMENTS, PROCEDURES, AND VERIFICATION TECHNIQUES. NASA SP-3072, 1972.

This survey of the oxygen system cleaning specifications from 23 industrial and government sources may be helpful in oxygen system design and operation.

Schmidt, A. F.: ASRDI OXYGEN TECHNOLOGY SURVEY. III - HEAT TRANSFER AND FLUID DYNAMICS. NASA SP-3076, 1972.

A compilation of evaluated reports and publications with direct applicability to oxygen systems.

Belles, Frank E.: HIGH PRESSURE OXYGEN UTILIZATION BY NASA. AIChE meeting, March 11 - 15, 1973, NASA TM X-68203, 1973.

Presents an overall view of the research studies that ASRDI is sponsoring on oxygen compatibility at high pressure.

Lapin, A. (Air Products and Chemicals, Inc., Allentown, Pa): LIQUID AND GASEOUS OXYGEN SAFETY REVIEW, Vols. I, II, III, and IV, NASA CR-120922, 1972.

A thorough and detailed study of Air Products and Chemicals, Inc. and Air Products Ltd. practices in the design and use of equipment in oxygen service, was performed. The report includes liquid and gaseous oxygen safety review information covering material compatibility, operational hazards, maintenance programs, systems emergencies, and accident/incident investigations and reports, and a set of references.

Ordin, P. M.: RESEARCH ON IGNITION AND COMBUSTION IN OXYGEN SYSTEMS. Compressed Gas Association Annual Meeting, April 17-18, 1973, NASA TM X-68223, 1973.

Ignition and combustion research in oxygen systems under the sponsorship of the NASA Aerospace Safety Research and Data Institute (ASRDI) is described. Preliminary results of ignition of nonmetallic materials by electric arc and mechanical impact are presented. Ignition by a resonant process involving repeated shock waves has been demonstrated and some of the results included. In addition, results of studies concerned with ignition due to the rapid rupture of metal films and diaphragms are reviewed.

Burning rate studies of three nonmetallic materials in oxygen enriched environments were completed and the results presented. A brief description of these combustion studies under zero gravity is also included. These results are compared to combustion under one gravity.

II. FIRE SAFETY

Kuvshinoff, Boris W. (Applied Physics Lab), McLeod, Stephen B., Katz, Richard G. (National Bureau of Standards): DIRECTORY OF WORKERS IN THE FIRE FIELD, First Edition. NASA CR-121149, 1973.

This Directory is a list of workers engaged in fire research, their addresses and affiliations, and their principal fields of activity. For purposes of this directory, fire science is taken to be the body of knowledge, art, and skill related to the investigation, analysis, and interpretation of the phenomena of unwanted fires and the evaluation of materials, methods, systems, and equipment related to fire safety, prevention, detection, and suppression.

Robertson, A.F.; Rappaport, Miriam W. (National Bureau of Standards): FIRE EXTINGUISHMENT IN OXYGEN ENRICHED ATMOSPHERES. NASA CR-121150.

This report reviews the current state-of-the-art of fire suppression and extinguishment techniques in oxygen enriched atmosphere. Four classes of extinguishment action are considered: cooling, separation of reactants, dilution or removal of fuel, and use of chemically reactive agents. Current practice seems to show preference for very fast acting water spray applications to all interior surfaces of Earth-based chambers.

Heine, Donald A. (North Central Airlines); and Brenneman, James J. (United Air Lines): THE CLEVELAND AIRCRAFT FIRE TESTS, Jul 24 - 25, 1968.

The objective of Phase II (July 24 - 25, 1968) of the Cleveland Fire Tests was to determine how far we could progress in reducing fire temperatures and toxic gases in a so-called ultimate cabin with the use of improved cabin finishing materials. Many of the materials used are only available in pilot plant quantities and some can even be considered laboratory curiosities. Phase II was conducted to determine if survival time in a postcrash fire environment could be appreciably extended by the use of materials with improved fire-resistant characteristics. A secondary objective was to determine the effect of a fire barrier installed between the skin of the aircraft and the occupied portion of the cabin to impede the progression of a fire.

III. ACCIDENTS/INCIDENTS

Anon. (General Electric Co., Daytona Beach): MANNED SPACE PROGRAMS ACCIDENT/INCIDENT SUMMARIES (1963-1969). NASA CR-120998, 1970.

This compilation of 508 mishaps, assembled from company and NASA records, covers several years (1963-69) of Manned Space Flight Activity. The purpose is to provide information to be applied towards accident prevention.

Anon. (Cranston Research, Inc.) MANNED SPACE PROGRAMS ACCIDENT/INCIDENT SUMMARIES (1970-1971). NASA CR-120999, 1972.

This compilation of 223 mishaps was assembled from company and NASA records covering the accident/incident experience in 1970-71 in the Manned Space Flight Programs. It is the companion volume to NASA CR-120998. The objective of this summary is to make available to Government agencies and industrial firms the lessons learned from these mishaps. A description, cause, and recommemded preventive action is given in each accident/incident summary.

Ordin, Paul M.: MISHAPS WITH OXYGEN IN NASA OPERATIONS. Oxygen Compressors and Pumps Symposium, Atlanta, Georgia, November 9 - 11, 1971.

This presentation covers information from a substantial number of oxygen mishaps obtained primarily from NASA and contractor records. Information from several Air Force records, concerning oxygen accidents involving aircraft operations, are also included. The description of the mishaps and their causes, with both liquid and gaseous (LOX and GOX) in ground test facilities and space vehicle systems are included in appendix A.

Siewert, R. D.: EVACUATION AREAS FOR TRANSPORTATION ACCIDENTS INVOLVING PROPELLANT TANK PRESSURE BURSTS. 1972 JANNAF Propulsion Meeting. New Orleans, Nov. 27 - 29, 1972.

Evacuation areas are defined for those transportation accidents where volatile chemical propellant tanks are exposed to fire in the wreckage and eventually explode with consequent risks from fragments in surrounding populated areas. An evacuation area with a minimum radius of 600 meters (2000 ft) is recommended to limit the statistical probability of fatality to one in 100 such accidents. The result of this study was made possible by the derivation of a distribution function of distances reached by fragments from bursting chemical car tanks. Data concerning fragments were obtained from reports of tank car pressure bursts between 1958 and 1971.

IV. TOXIC SPILLS

Siewert, R. D.: A METHOD FOR DEFINING DOWN-WIND EVACUATION AREAS FOR TRANSPORTATION ACCIDENTS INVOLVING TOXIC PROPELLANT SPILLS. 1972 JANNAF Propulsion Meeting, New Orleans, La., Nov. 27 - 29, 1972.

Evacuation areas for accidental spills of toxic propellants along the rail and highway shipping routes are defined to help local authorities reduce risks to people from excessive vapor concentrations.

V. AVIATION SAFETY

ROTOR BURST

DeLucia, R.A.; Mangano, G.J. (Naval Air Propulsion Test Center): ROTOR BURST PROTECTION PROGRAM: STATISTICS ON AIRCRAFT GAS ENGINE FAILURES THAT OCCURRED IN COMMERCIAL AVIATION DURING 1971. NASA CR-121151, 1973.

This report presents statistics on gas-turbine rotor failures that have occurred in commercial aviation during 1971. These data were analyzed to establish (a) the incidence of contained and uncontained rotor bursts, (b) the failure distribution with respect to engine component, i.e., fan, compressor, or turbine, (c) the type of rotor fragment (disk, rim, or blade) typically generated at failure, (d) the cause of failure, and (e) the type of engine involved.

Wu, Richard W-H; Witmer, Emmett A. (Massachusetts Institute of Technology): COMPUTER PROGRAM JET 3 - TO CALCULATE THE LARGE ELASTIC-PLASTIC DYNAMICALLY-INDUCED DEFORMATIONS OF FREE AND RESTRAINED, PARTIAL, AND/OR COMPLETE STRUCTURAL RINGS. NASA CR-120993.

This report presents a user-oriented FORTRAN IV computer program, called JET 3, which uses the spatial finite-element and timewise finite-difference method. The program can be used to predict the large two-dimensional elastic-plastic transient Kirchhoff deformations of a complete or partial structural ring, with various support conditions and restraints, subjected to a variety of initial velocity destributions and externally applied transient forcing functions. The geometric shapes of the structural ring can be circular or arbitrarily curved and with variable thickness. Strain-hardening and strain-rate effects of the material are taken into account.

Zirin, Robert M.; Witmer, Emmett A. (Massachusetts Institute of Technology): EXAMINATION OF THE COLLISION FORCE METHOD FOR ANALYZING THE RESPONSES OF SIMPLE CONTAINMENT/DEFLECTION STRUCTURES TO IMPACT BY ONE ENGINE ROTOR BLADE FRAGMENT. NASA CR-120952, 1972.

An approximate collision analysis, termed the collision-force method, has been developed for studying impact-interaction of an engine rotor blade fragment with an initially circular containment ring .

Mangano, G.J. (Naval Air Test Propulsion Center): ROTOR BURST PROTECTION PROGRAM - PHASE VI AND VII: EXPLORATORY EXPERIMENTATION TO PROVIDE DATA FOR THE DESIGN OF ROTOR BURST FRAGMENT CONTAINMENT RINGS. NASA CR-120962, 1972.

This report presents the results of exploratory experimentation that was conducted in the NAPTC Rotor Spin Facility to provide criteria for the design of turbomachine rotor-burst-fragment containment rings. High-speed photography was used to study containment processes involving freely supported rings of different materials and a variety of rotor and flat disk fragments.

Wu, Richard W-H; Witmer, Emmett, A. (Massachusetts Institute of Technology): FINITE-ELEMENT ANALYSIS OF LARGE TRANSIENT ELASTIC-PLASTIC DEFORMATION OF SIMPLE STRUCTURES, WITH APPLICATION TO THE ENGINE ROTOR FRAGMENT CONTAINMENT/DEFLECTION PROBLEM. NASA CR-120886, 1972.

One of the principal objectives is to improve the finite-element method for predicting the large-deformation elastic-plastic transient responses of structures where efficient and accurate strain predictions are of particular interest to the aerospace designer/analyst. However, being a first step in this development, the present study is devoted largely to planar structures.

Leech, John W.; Witmer, Emmett A.; and Yeghiayan, Raffi, P. (Massachusetts Institute of Technology): DIMENSIONAL ANALYSIS CONSIDERATIONS IN THE ENGINE ROTOR FRAGMENT CONTAINMENT/DEFLECTION PROBLEM. NASA CR-120841, 1971.

Dimensional analysis techniques are described and applied to the containment and deflection problem of bursting high-rpm rotating parts of turbojet engines.

Chiarito, Patrick T.: STATUS OF ENGINE ROTOR BURST PROTECTION PROGRAM FOR AIRCRAFT. NASA SP-270, 1971, pp. 75-88.

The extensive use of turbomachinery in aircraft has been accompanied by the danger that a high-speed rotor will occasionally fail and the uncontrolled fragments will damage equipment and threaten passenger safety. Accordingly, NASA is sponsoring a coordinated theoretical and experimental research program to develop criteria for the design of practical devices to protect the aircraft from serious damage. Means to contain rotor fragments as well as to deflect them from critical aircraft components are being studied.

McCallum, Bruce, R.; Leech, John W,; and Witmer, Emmett A. (Massachusetts Institute of Technology): ON THE INTERACTION FORCES AND RESPONSES OF STRUCTURAL RINGS SUBJECTED TO FRAGMENT IMPACT. NASA CR-72801, 1970.

A FORTRAN IV computer program, called JET 2, can be used to predict the large, two-dimensional elastic-plastic dynamic Kirchhoff deformations of a free, multilayer, hard-bonded, multimaterial, isothermal, circular ring subjected to an intial impulse loading followed by an arbitrary time-dependent forcing function. The forcing function can be defined to simulate the forces that result from the interaction of burst rotor fragment or fragments and a containment ring. Strain-hardening and strain-rate effects of the ring material are taken into account. Tests for interlayer bond failure can be made if desired.

McCallum, Bruce R.: SIMPLIFIED ANALYSIS OF A TRIFRAGMENT ROTOR DISK INTERACTION WITH A CONTAINMENT RING. AIAA Journal of Aircraft, Column 7, No. 3, May-June 1970, pp. 283-285.

Spin-pit tests have been performed at the Naval Air Propulsion Test Center, Philadelphia, Pa., on 15-in.-i.d. steel rings of various thicknesses using comparatively nondeforming steel fragments to evaluate the possibility of using an inexpensive standard fragment generator in future parametric studies. The purpose of these parametric studies would be to test the merits of various materials to be used for jet engine burst rotor containment devices.

McCallum, Bruce R.; Leech, John W.; and Witmer, Emmett A. (Massachusetts Institute of Technology): PROGRESS IN THE ANALYSIS OF JET ENGINE BURST-ROTOR CONTAINMENT DEVICES, NASA CR-107900. 1969.

A FORTRAN IV computer program is presented that can be used to predict the large two-dimensional elastic-plastic dynamic deformations of a free, non-uniformly heated circular ring subjected to an initial impulse loading followed by a time-dependent forcing function. The forcing function could be defined to simulate the forces that result from the interaction of a burst rotor blade and a containment ring.

Martino, A.A.; and Mangano, G.J.: ROTOR BURST PROTECTION PROGRAM, Final Report. NASA CR-106801, 1969.

The NASA-sponsored Rotor Burst Protection Program reports its continuing study into the kinetics of intentionally failed rotors within fragment control systems and the influence of certain important system parameters on the containment/control process. High-speed photographs have recorded the complex action of bladed rotors which more closely approximate realistic turbomachinery operating conditions than did the earlier RBPP testing.

LIGHTNING

Plumer, J.A. (General Electric, Pittsfield): ANALYSIS AND CALCULATION OF LIGHTNING-INDUCED VOLTAGES IN AIRCRAFT ELECTRICAL CIRCUITS, Final Report. Contract NAS3-14836, 1972.

The report describes an analytical investigation of techniques to calculate the transfer functions relating lightning-induced voltages in aircraft electrical circuits to aircraft physical characteristics and lightning current parameters. The analytical work was carried out concurrently with an experimental program of measurements of lightning-induced voltages in the electrical circuits of an F89-J aircraft.

Walko, L.C. (General Electric, Pittsfield): A TEST TECHNIQUE FOR MEASURING LIGHTNING-INDUCED VOLTAGES ON AIRCRAFT ELECTRICAL CIRCUITS, Final Report. Contract NAS3-14836, 1972.

The report describes the development of a test technique used for the measurement of lightning-induced voltages in the electrical circuits of a complete aircraft. The resultant technique uses a portable device known as a transient analyzer, which is capable of generating unidriectional current impulses similar to lightning current surges, but at a lower current level.

Kosvic, T.C.; Helgeson, N.L.; and Gerstein, M. (Dynamic Science): IGNITION OF FUEL VAPORS BENEATH TITANIUM AIRCRAFT SKINS EXPOSED TO LIGHTNING. NASA CR-120827, 1971.

Hot-spot and puncture ignition of fuel vapors by simualted lightning discharges was studied experimentally. The influences of skin coating, skin structure, discharge polarity, skin thickness, discharge current level, and current duration were measured and interpreted. Ignition thresholds are reported for titanium alloy constructed as sheets, sheets coated with sealants, and sandwich skins. An analytical model was developed to provide insight into the mechanism controlling the ignition of fuel tank ullage vapors.

Hacker, Paul T.: LIGHTNING-INDUCED VOLTAGES IN AIRCRAFT ELECTRICAL CIRCUITS. NASA SP-270, 1971, pp 61-73.

A study was conducted to determine the magnitude of induced voltages and their relation to the characteristics of the lightning discharges and to the physical and electrical characteristic of the aircraft and its electrical systems. The investigation was performed with a wing of an F-89 airplane and a simulated lightning facility. The induced voltages were measured for some circuits. Simulated lightning characteristics were of sufficient magnitude to adversely affect sensitive avionics.

Hacker, Paul T. (ASRDI); Plumer, J.A. (General Electric Co., Pittsfield): MEASUREMENTS AND ANALYSIS OF LIGHTNING-INDUCED VOLTAGES IN AIRCRAFT ELECTRICAL CIRCUITS. 1970 Lightning and Static Electric Conference, Dec. 1970.

A series of measurements were made of voltages induced in electrical circuits within a metallic aircraft wing by fullscale simulated lightning currents flowing through its skin and structure. The measured data were mathematically analyzed to enable the determination of voltages across load impedances to which the circuits might be connected elsewhere in the aircraft. Relationships between induced voltages and lightning current, and wing structural and circuit parameters were determined. Induced voltages of magnitudes likely to cause damage or interference with avionics were measured.

Lloyd, K.J.; Plumer, J.A.; and Walko, L.C. (General Electric Co., Pittsfield): MEASUREMENTS AND ANALYSIS OF LIGHTNING-INDUCED VOLTAGES IN AIRCRAFT ELECTRICAL CIRCUITS. NASA CR-1744, 1970.

The report describes an experimental investigation of voltages induced by lightning in aircraft electrical circuits. An extensive series of measurements was made of voltages induced in circuits within a metallic aircraft wing by full-scale simulated lightning currents flowing through its skin and structure.

Hacker, Paul T,; and Plumer, J.A. (General Electric Co., Pittsfield): MEASUREMENTS AND ANALYSIS OF LIGHTNING-INDUCED VOLTAGES IN AIRCRAFT ELECTRICAL CIRCUITS. Paper No. 700924, Society of Automotive Engineers.

A series of measurements was made of voltages induced in electrical circuits within a metallic aircraft wing by fullscale simulated lightning currents flowing through its skin and structure.

TIRES AND BRAKES

Miller, C.D.; and Pinkel, I.I.: ALUMINUM RUNWAY SURFACE AS POSSIBLE AID TO AIRCRAFT BRAKING. NASA TN D-7186, 1973.

Several concepts are described for use singly or in combination to improve aircraft braking. All involve a thin layer of aluminum covering all or part of the runway. Advantages would derive from faster heat conduction from the tire-runway interface.

Peterson, Marshall B.; Ho, Ting-Long (Rensselaer Polytechnic Institute): CONSIDERATION OF MATERIALS FOR AIRCRAFT BRAKES. NASA CR-121116, 1972.

An exploratory investigation concerning materials and their properites for use in aircraft brakes is reported. Primary consideration was given to the heat dissipation and the frictional behavior of materials. Used brake and rotors were analyzed as part of the investigation.

Nybakken, G.H.; Collart, D.Y.; Staples, R.J.; Lackey, J.I.; Clark, S.K.; Dodge, R.N. (University of Michigan): PRELIMINARY MEASUREMENTS ON HEAT BALANCE IN PNEUMATIC TIRES. NASA CR-121239, 1973.

A variety of tests was undertaken to determine the nature of heat generation associated with a pneumatic tire operating under various conditions. The tests were conducted to determine the magnitude and distribution of internally generated heat in the rubber and ply fabric in an automobile tire operating under conditions of load, pressure, and velocity representative of normal operating conditions.

FUELS

Weiss, S.: THE USE OF HYDROGEN FOR AIRCRAFT PROPULSION IN VIEW OF THE FUEL CRISIS. NASA Research and Technology Advisory Committee on Aeronautical Operating Systems, Ames Research Center, Moffett Field, California, March 7 - 8, 1973 (NASA TM X-68242).

Some factors influencing the technical feasibility of operating a liquid hydrogen-fueled airplane are discussed in light of the projected decrease of fossil fuels. Coal will be heavily relied on to meet future energy needs . Near the turn of this century nuclear fuels should become the major source of energy. Other sources of energy, sach as wind, tidal, solar, and geothermal, are briefly mentioned. Interest has been generated in exploiting the potential of liquid hydrogen (LH_2) as an aircraft fuel. Cost studies of LH_2 production show it to be more expensive than presently used fuels. Regardless, LH_2 is viewed as an attractive aircraft fuel because of the potential performance benefits it offers. Some of the factors influencing LH_2 fuel tank design, pumpimg, heat exchange, and flow regulation are discussed.

Hibbard, R.R.; and Hacker, P.T.: A REEVALUATION OF THE RELATIVE FIRE HAZARDS OF JET A AND JET B FOR COMMERCIAL FLIGHT. NASA Technical Memorandum X-71437, 1973.

This reevaluation was made to determine whether there are any significant differences in the relative fire hazards between the kerosene type Jet A and the more volatile Jet B aircraft gas turbine fuels. These fuels were compared with respect to flammable hazards under all conditions, i.e., in ground handling, in flight, spillage, and after a survivable crash. The fire hazards after a survivable crash are clearly greater with Jet B. Five factors were considered and Jet A is either slightly or significantly the safer fuel for all five. It is concluded that Jet A is the preferred fuel for commercial operations.

VI. STRUCTURAL FAILURES

Hall, L. R.; and Finger, R.W.: FRACTURE AND CRACK GROWTH RESISTANCE STUDIES OF 304 STAINLESS STEEL WELDMENTS RELATING TO RETESTING OF CRYOGENIC VESSELS. NASA CR-121025, 1973.

In this experimental program, welding procedures were typical of those used in full-scale vessel fabrication. Fracture resistance survey tests were conducted in room temperature air, liquid nitrogen, and liquid hydrogen. Load-unload, sustained load, and cyclic load tests were performed in air or hydrogen gas, liquid nitrogen and liquid hydrogen using surface-flawed specimens containing weld centerline cracks. Results were used to evaluate the effectiveness of periodic proof overloads in assuring safe and reliable operation of over-the-road cryogenic dewars.

Carpenter, J.L., Jr.; and Moya, N.: THESAURUS OF TERMS FOR INFORMATION ON MECHANICS OF STRUCTURAL FAILURE. NASA CR-121199, 1973.

This thesaurus has approximately 700 subject terms used to describe six problem areas in the mechanics of structural failure. The purpose of the thesaurus is to provide a list of key words that afford effective retrieval of the information regarding failure modes and mechanics for aerospace structures.

Carpenter, J.L., Jr.; and Moya, N.: REGISTER OF EXPERTS FOR INFORMATION ON MECHANICS OF STRUCTURAL FAILURE. NASA CR-121200, 1973.

This register lists approximately 150 experts from 60 organizations who have published results of theoretical and/or experimental research related to six problem areas in the mechanics of structural failure. The purpose of the register is to identify sources of dependable information regarding failure modes and mechanics of aerospace structures.

Carpenter, J.L., Jr.; and Denny, F.J.: REGISTER OF SPECIALIZED SOURCES FOR INFORMATION ON THE MECHANICS OF STRUCTURAL FAILURE. NASA CR-121201, 1973.

This register lists alphabetically 22 specialized information sources that generate information relative to six problem areas in aerospace mechanics of structural failure. Activities listed perform basic or applied research related to the mechanics of structural failure and publish the results of such research.

Carpenter, J.L., Jr.; Moya, N.; Shaffer, R.A.; and Smith, D.M.:
BIBLIOGRAPHY OF INFORMATION ON MECHANICS OF STRUCTURAL FAILURE.
NASA CR-121201, 1973.

This bibliography comprises approximately 1500 reference citations related to six problem areas in the mechanics of failure in aerospace structures. The bibliography represents a search of the leterature published in the 10-year period 1962-72 and is largely limited to documents published in the United States. Listings are subdivided into the six areas: (1) Life prediction of structural materials, (2) fracture toughness data, (3) fracture mechanics analyziz, (4) hydrogen embrittlement, (5) protective coatings, and (6) composite materials. An author index is included.

VII. NUCLEAR SYSTEMS

General Electric Co., Space Division, Valley Forge Space Center: MANNED SPACE FLIGHT NUCLEAR SYSTEM SAFETY, Volume VII - Literature Review. Part 1 - Literature Search and Evaluation, Final Report. Document No. 72SD4201-7-1, 1972.

VIII. FLUID FLOW

Baumeister, K.J.; Graham, R.W.; and Henry, R.E.: MOMENTUM FLUX IN TWO PHASE TWO COMPONENT LOW QUALITY FLOW. NASA TM X-68038, 1972.

In two-phase flow systems line losses comprise frictional and momentum pressure drops. For design purposes, it would be desirable to estimate the line losses employing a one-dimensional calculation. Two methods for computing one-dimensional momentum flux at a test section discharge station are compared with the experimental value for a range of two-phase flow conditions. The one-dimensional homogeneous model appears to be more accurate generally in predicting the momentum than the variable slip model.

Watts, R.G.; and Hsu, Y.Y.: COMPRESSIBILITY OF A TRANSLATING BUBBLE IN AN OSCILLATING PRESSURE FIELD. Submitted to Journal of Fluid Mechanics, 1972.

Hendricks, R.C.; Simoneau, R.J.; and Ehlers, R.C.: CHOKED FLOW ON FLUID NITROGEN WITH EMPHASIS ON THE THERMODYNAMIC CRITICAL REGION. NASA TM X-68107, 1972.

Experimental measurements of critical flow rate and pressure ratio for notrogen flowing through a nozzle are presented. Data for selected stagnation isotherms from 87.5 to 234 K with pressures to 9.3 MN/m^2 are compared with an equilibrium model with real fluid properties and also a nonequilibrium model. Critical flow pressure ratio along an isotherm tends to peak while the flow rate indicates an inflection. The point is closely associated with the transposed critical temperature and represents a change in the fluid structure.

Simon, F.F.; and Hsu, Y.Y.: EFFECT OF CONTACT ANGLE HYSTERESIS ON MOVING LIQUID FILM INTEGRITY. NASA TM X-68071, 1972.

A study was made of the formation and breakdown of a water film moving over solid surfaces (Teflon, Lucite, stainless steel, and copper). The flow rate associated with film formation was found to be higher than the flow rate at which film breakdown occurred. The difference in the flow rates for film formation and film breakdown was attributed to contact angle hysteresis. Analysis and experiment, which are in good agreement, indicated that film formation and film breakdown are functions of the advancing and receding angles, respectively.

Simon, F.F.; and Hsu, Y.Y.: WETTING DYNAMICS OF EVAPORATION DROPS ON VARIOUS SURFACES. NASA TM X-67913, 1971.

Shape histories of water deops evaporating at room temperature on copper, Lucite, stainless steel, and Teflon were recorded. The drops were observed to go through three stages. In the first stage the interface radius remained constant while the contact angle reduced with decreasing volume, until the receding angle is reached. In the second stage, the radius decreased almost linearly with time while the contact angle remained a little less than the receding angle. In the third stage both radius and contact angle reduced rapidly. The relative length of each stage is determined by the type of surface. For a highly wettable surface, Stage I dominated; for a very nonwettable surface, Stage II dominated. An analysis is presented enabling the prediction of shape history of a drop, provided the evaporation rate and flow resistance over the surface are given.

Baumeister, K.J.; and Simon, F.F.: LEIDENFROST TEMPERATURE -- ITS CORRELATION FOR LIQUID METALS, CRYOGENS, HYDROCARBONS, AND WATER. For Transactions of ASME, 1972.

Sengers, J.V. (University of Maryland): TRANSPORT PROPERTIES OF GASES AND BINARY LIQUIDS NEAR THE CRITICAL POINT. NASA CR-2112, 1972.

A status report is presented on the anomalies observed in the behavior of transport properties near the critical point of gases and binary liquids. The shear viscosity exhibits a weak singularity near the critical point. An analysis is made of the experimental data for those transport properties (thermal conductivity, and thermal diffusivity mear the gas-liquid critical point and binary diffusion coefficient near the critical mixing point,) that determine the critical slowing down of the thermodynamic fluctuations in the order parameter. The asymptotic behavior of the thermal conductivity appears to be closely related to the asymptotic behavior of the correlation length. The experimental data for the thermal conductivity and diffusivity are in substantial agreement with current theoretical predictions.

Hsu, Y.Y.: REVIEW OF CRITICAL FLOW RATE PROPAGATION OF PRESSURE PULSE AND SONIC VELOCITY IN TWO PHASE MEDIA. NASA TN D-6814, 1972.

For single-phase media, the critical discharge velocity, the sonic velocity, and the pressure pulse propagation velocity can be expressed in the same from by assuming isentropic, equilibria precesses. In two-phase mixtures the same concept is not valid due to the existence of interfacial transports of momentum, heat, and mass. Thus, the three velocities should be treated differently and separately for each particular condition, taking into account the various

transport processes involved under that condition. This report reviews various attempts to predict the critical discharge rate or the propagation velocities by considering slip ratio (momentum change), evaporation (mass and heat transport), flow pattern, etc. Experimental data were compared with predictions based on various theorems. The importance is stressed of the time required to achieve equilibrium as compared with the time available during the process, for example, of passing a pressure pulse.

Simoneau, R.J.: VELOCITY AND TEMPERATURE PROFILES IN NEAR-CRITICAL NITROGEN. NASA TM X-52988, 1971.

Boundary-layer velocity and temperautre profiles were measured in nitrogen near its thermodynamic critical point flowing turbulently upward over a heated flat plate with constant surface hear flux. The measurements were made with a combination thermocouple and pitot-static probe. Data were taken with the fluid in the boundary layer spanning the critical temperature and also at the same operating conditions, except with the boundary layer at temperatures away from the critical temperature. The results showed that the near-critical velocity profiles were quite different, exhibiting a maximum between the wall and free stream. The near-critical profile had a much larger Grashof number, suggesting that a strong body force effect was present. The data are examined in terms of the velocity and temperature profile response to variations in the system parameters. Proximity to the critical point appears to exaggerate body forces even at quite high Reynolds numbers.

Hendricks, R.C.; and Simoneau, R.J.: APPLICATION OF THE PRINCIPLE OF CORRESPONDING STATES TO TWO-PHASE CHOKED FLOW. Seventy-fourth National Meeting of the American Institute of Chemical Engineers, New Orleans, Louisiana, March 11 - 15, 1973, (NASA TM X-68193).

If the possibility of applying the principle is valid, designers, using data from other fluids to support them, could apply the theory of their choice to fluids where there are little or no data, such as oxygen. Two-phase critical flow and critical flow pressure ratio of simple fluids through a nozzle are shown to nearly obey the principle of corresponding states. The normalization of corresponding states presented is supported by nitrogen and methane two-phase choked flow data. Since the reduced curves for nitrogen, oxygen, and methane are so close, it is felt that oxygen two-phase choked flow can be predicted using corresponding states reduction and relying on nitrogen and methane data to establish the appropriate theory to use.

Hendricks, R.C.; Simoneau, R.J.; and Hsu, Y.Y. (NASA Lewis Research Center): A VISUAL STUDY OF RADIAL INWARD CHOKED FLOW OF LIQUID NITROGEN. TECHNICAL PAPER proposed for presentation at Cryogenic Engineering Conference Atlanta, Georgia, August 8 - 10, 1973 (NASA TM X-68283).

Data and high speed movies were acquired on pressurized subcooled liquid nitrogen flowing radially inward through a 0.0076-cm (3-mil) gap. The stagnation pressure ranged from 0.7 to 4 MN/m^2 ($0.2 \leq P/P_c \leq 1.2$). The results of this qualitative study indicate that following: (1) steady radial inward choked flow appears equivalent to steady choked flow through axisymmetric nozzles; (2) Transient choked flows through the radial gap are not uniform, and the discharge pattern appears as nonuniformimpinging jets; (3) the critical mass flow rate data for the transient case appear different from those for the steady case. On the mass flow rate versus pressure map, the slope and separation of the isotherms appear to be less for transient than for steady radial choked flow.

Sengers, J.M.H. (National Bureau of Standards); Greer, W.L.; and Sengers, J.V. (University of Maryland): SCALED PARAMETRIC EQUATION-OF-STATE FOR OXYGEN IN THE CRITICAL REGION. Presented at the Cryogenic Engineering Conference, Atlanta, Georgia, August 8 - 10, 1973.

A method is described for fitting critical-region equation-of-state data with a particular scaled equation-of-state, the so-called linear model. The method has been applied to the density profiles observed by Weber in the critical region of oxygen. The linear model is shown to fit these data well, except for a small region on the critical isochore close to T_c. The optimized critical exponents, however, do not agree very well with those from Weber's power-law analysis. Some sets of equation-of-state parameters are presented as starting points for further thermodynamic calculations on oxygen.

IX. ZERO GRAVITY COMBUSTION

Cochran, T.H.; Petrash, D.A.; Andracchio, C.R.; and Sotos, R.G.: BURNING OF TEFLON-INSULATED WIRES IN SUPERCRITICAL OXYGEN AT NORMAL AND ZERO GRAVITIES. NASA TM X-2174, 1971.

An experimental program was conducted to investigate the burning characteristics of Teflon-insulated nickel wires in supercritical oxygen in normal and zero gravities. The zero-gravity environment was obtained in a drop tower which made available 5 seconds of test time. The results indicate that the Teflon burned in both normal and zero gravities. However, the flame propagation rate in zero gravity was smaller than in normal gravity.

Cochran, T.H.: EXPERIMENTAL INVESTIGATION OF LAMINAR GAS JET DIFFUSION FLAMES IN ZERO GRAVITY. NASA TN D-6523, 1972.

An experimental program was conducted to study the burning of laminar gas jet diffusion flames in a zero-gravity environment. The tests were conducted in the Lewis Research Center's 2.2-Second Zero-Gravity Facility and were a part of a continuing effort investigating the effects of gravity on basic combustion processes. The photographic results indicate that steady-state gas jet diffusion flames existed in zero gravity, but they were geometrically quite different than their normal-gravity counterparts. Methane-air flames were found to be approximately 50 percent longer and wider in zero gravity than in normal gravity.

Haggard, J.B.; and Cochran, T.H.: STABLE HYDROCARBON DIFFUSION FLAMES IN A WEIGHTLESS ENVIRONMENT. Combustion Science and Technology, vol. 5, no. 6, Aug. 1972, Pg. 291.

An experimental investigation of stable laminar ethylene and propylene diffusion flames burning on a nozzle in weightlessness was performed in the Lewis 2.2-Second Drop Tower. For a range of low flow conditions, visual evidence indicated that the flames reaction zone was burning over a wide range of combustion rates; however, for the purposes of correlating flame length, the stoichiometric burning rate appeared adequate. It was found that, if Re is the ambient pure fuel Reynolds number based on nozzle radius, Sc is the ambient pure fuel Schmidt number, and c_F is the mole fraction of fuel burning stoichiometrically in air, the ratio of flame length to nozzle radius was predicted and experimentally verified to be proportional to $Sc^{1/2}\ Re\ ln^{1/2}\ (1/(1-c))$.

Edelman, R.B.; Fortune, O.; and Weilerstein, G. (General Applied Science Lab.): ANALYTICAL STUDY OF GRAVITY EFFECT ON LAMINAR DIFFUSION FLAMES. NASA CR-120921, 1972.

A mathematical model is presented for the description of axisymmetric laminar-jet diffusion flames. The analysis includes the effects of inertia, viscosity, diffusion, gravity, and combustion. These mechanisms are coupled in a boundary-layer formulation, and solutions are obtained by an explicit finite-difference technique. A dimensional analysis shows that the maximum flame width radius, velocity, and thermodynamic state characterize the flame structure. Comparisons with experimental data showed excellent agreement for steady-state, low Reynolds number, zero-gravity flames. Kinetics effects and radiation are shown to be the primary mechanisms responsible for this descrepancy. Additional factors are discussed including ellipticity and transient effects.

Haggard, J.B., Jr.; and Cochran, T.H.: HYDROGEN AND HYDROCARBON DIFFUSION FLAMES IN A WEIGHTLESS ENVIRONMENT. NASA TN D-7165, 1973.

An experimental investigation was performed on laminar hydrogen-, ethylene-, and propylene- air diffusion flames burning in a weightless environment. The flames burned on nozzles with radii ranging from 0.051 to 0.186 cm with fuel Reynolds numbers at the nozzle exit from 9 to 410. Steady-state diffusion flames existed in a weightless environment for all the fuel tested. A correlation was obtained for their axial length as a function of Schmidt number, Reynolds number, and stoichiometric mole fraction. The maximum flame radii were correlated with the ratio of nozzle radius to average fuel velocity. The flames of ethylene and propylene on nozzles with radii 0.113 cm or larger appeared to be constantly changing color and/or length throughout the test. No extinguishment was observed for any of the gases tested within the 2.2 seconds of weightlessness.

X. MISCELLANEOUS

Mandel, George: THE AEROSPACE SAFETY RESEARCH AND DATA INSTITUTE'S OBJECTIVES AND PROGRAMS. NASA Technical Information Conference, Sep. 20 - 21, 1972.

This presentation covered ASRDI's mission and objectives as well as its scope. It also highlighted ASRDI's research projects and programs, publications, committee memberships, and the ASRDI Safety Data Bank.

Miller, C. David: DISTRIBUTION OF ERROR IN LEAST-SQUARES SOLUTION OF AN OVERDETERMINED SYSTEM OF LINEAR SIMULTANEOUS EQUATION. NASA TN D-6744, 1972.

Probability density functions are derived for the errors in the evaluation of unknowns by the least-squares method in an overdetermined system of nonhomogeneous linear equations, Coefficients of the unknowns are assumed correct and computational precision is assumed. A vector space is used, with a number of dimensions equal to the number of equations. An error vector is defined and assumed to have uniform distribution of orientation throughout the vector space. The density functions are shown to be insensitive to the biasing effects of the source of the system of equations.

Miller, C.D.: EMPIRICAL ANALYSIS OF UNACCELERATED VELOCITY AND MASS DISTRIBUTIONS OF PHOTOGRAPHIC METEORS. NASA TN D-5710, 1970.

An empirical analysis was performed on data for 2000 sporadic meteors. A bimodal log-normal equation was found for unaccelerated velocity distribution by empirical curve fitting to match observed velocity distributions for meteoroids within 10 ranges of mass, with due regard to failure of observation of faint meteors.

Miller, C.D.: METEROID HAZARD EVALUATION FOR SIMPLE STRUCTURES WITH VARIOUS ORIENTATIONS. NASA TN D-6056, 1970.

A statistical analysis was performed with use of Smithsonian Astrophysical Observatory's data on photographic meteors with use of weighting factors developed at Lewis for the correction of various biases involved in meteor photography. The analysis used an armor damage criterion supplied by Ames Research Center. Although the analysis was restricted to Earth's orbit about the Sun, implications are discussed regarding total population of meteoroids throughout the solar system. In Earth's orbit about the Sun, advantage was found for cylindrical armor extending in the solar direction and a plane sheet alined normal to apex of Earth Movement.

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